Propulsion Technology Assessment: Science and Enabling Technologies to Explore the Interstellar Medium

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Led by the Keck Institute for Space Studies at the California Institute of Technology, the Advanced Concepts Office at NASA's George C. Marshall Space Flight Center conducted a study to assess what low-thrust advanced propulsion system candidates, existing and near term, could deliver a small, Voyager-like satellite to our solar system's heliopause, approximately 100 AU from the center of the sun, within 10 years and within a 2025 – 2035 launch window. The advanced propulsion system trade study consisted of three candidates, including a Magnetically Shielded Miniature (MaSMi) Hall thruster, a solar sail and an electric sail. Two aerial densities, and thus characteristic accelerations, 0.426 mm/s^2 and 0.664 mm/s^2, were analyzed for the solar sail option in order understand the impact of near and long term development of this technology. Similarly, two characteristic accelerations, 1 mm/s^2 and 2 mm/s^2, were also analyzed for the electric sail option in addition to tether quantities of 10 and 20, respectively, and individual tether length of 20 km. A second analysis was conducted to determine what existing solid rocket motor kick stage(s) would be required to provide additional thrust at various points in the trajectory, assuming an earth departure characteristic energy capability provided by a Space Launch System (SLS) Block 1B vehicle architecture carrying an 8.4 meter payload fairing. Two trajectory profiles were considered, including an escape trajectory using a Jupiter gravity assist (*E-Ju*), and an escape trajectory first performing a Jupiter gravity assist followed by an Oberth maneuver around the sun and an optional Saturn gravity assist (*E-Ju-Su-Sa*). The Oberth maneuver would need to be performed very close to the sun, wherein this study assumed a perihelion distance of approximately 11 solar radii, or 0.05 AU, away from the surface. The heat shield technology required to perform this type of ambitious maneuver was assumed to be similar to that of NASA's Solar Probe Plus mission, which is slated to launch in July 2018. With respect to a SLS Block 1B earth departure characteristic energy capability of 100 km^2/s^2 for the *E-Ju* trajectory option, results indicated that compared to having no advanced propulsion system onboard, both the MaSMi Hall thruster and solar sail options subtract approximately 8 to 10 years from the total trip time while the electric sail outperforms all options by subtracting up to 20 years. With respect to an average kick stage velocity capability of 2.5 to 3.5 km/s at perihelion, the most sensitive segment of the *E-Ju-Su-Sa* trajectory option, results indicated that both the MaSMi Hall thrust and solar sail options only subtract 1 to 3 years from the total trip time whereas the electric sail again outperforms all other options by subtracting up to 5 years. In other words, if the Technology Readiness Level of an electric sail could be increased in time, this propulsion technology could not only enable a satellite to reach 100 AU in 10 years but it could potentially do so even faster. Completing such an ambitious mission in that short of a timespan would be very attractive to many as it would be well within the average career span of any of those involved.